Leeson 5 (Part A): Communication Elements

José M. Cámara and Miguel Cantera

(checam@ubu.es and macantera@ubu.es)

V. 1.3

Introduction

- Electronic devices need to communicate with one another.
- Communication may be required both internally and externally.
- Communication can take place over different physical media:
  - Electrical: cables, printed circuit boards
  - Optical
  - Electromagnetic (wireless communications)
- Some communication standards specify a particular physical medium, while others support several different media.
- To facilitate their study, we will use bus theory as a starting point.
- Bus concept: a communication channel that allows physically separated devices to exchange information.

Bus Classification (I)

- ***Parallelism***: Divides buses into two categories: serial buses, which transfer information over at most one line in each direction, and parallel buses, which transfer information simultaneously over several lines, typically one line per bit.
- ***Length*****:** Maximum distance between two devices connected through the bus. In many cases, a long maximum distance is desirable, although this generally comes at the expense of other performance characteristics.
- ***Width:*** Number of lines in the bus.
- ***Transfer Rate***: Rate at which information is exchanged, expressed in bits or bytes per unit of time. Bits are more commonly used for serial buses, while bytes are more commonly used for parallel buses.
- ***Connection Capacity*****:** Maximum number of devices that can be connected to the bus. Due to electrical or functional limitations, the number of devices that can be connected is limited.

Bus Classification (II)

- ***Physical Medium:*** Physical structure through which information is transmitted: ribbon cable, coaxial cable, twisted pairs, optical fiber, printed circuit board, etc.
- ***Synchronization:*** Method used to synchronize the transmitter and receiver clocks. This also divides buses into two categories:
  - **Synchronous:** The clock is transmitted together with the information, either on a separate line or embedded in the transmitted signal
  - **Asynchronous:** A synchronization signal is provided from which the receiver can recover or regenerate the clock
- ***Error Detection and Correction Capability:*** The bus may include redundant information intended to detect and even correct transmission errors. This is particularly important in high-speed buses and over long distances, where the probability of transmission errors is greater.
- ***Arbitration***: Method used to resolve conflicts when more than one device attempts to take control of the bus at the same time. **Centralized:** Requires an arbiter; **Distributed:** Does not require a central arbiter

Bus Description

- ***Mechanical Characteristics:*** Bus medium, number of lines, connector type.

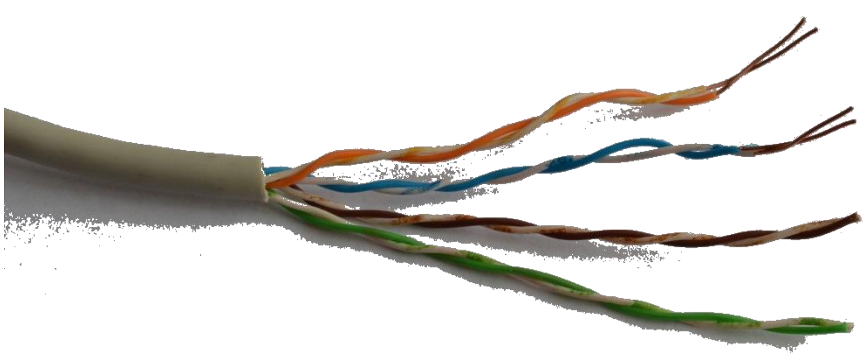
- ***Electrical (or Optical) Characteristics:*** Bus signal voltage and current levels, maximum distances and connection capacity; need for repeaters and associated distance limitations; transmission-line behavior; need for termination and required termination-impedance characteristics.

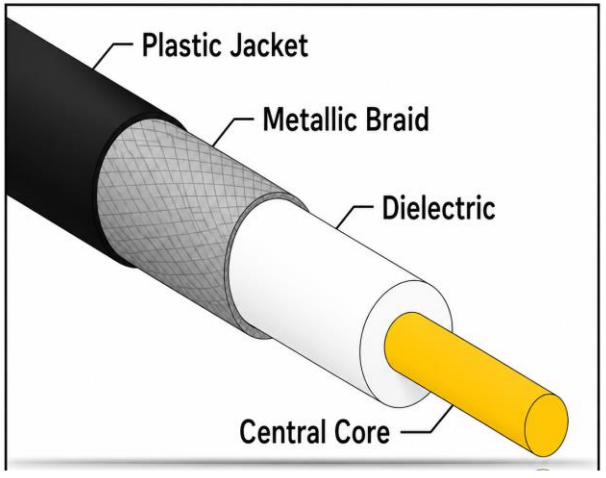
- ***Functional Characteristics:*** Function of all bus lines, types of bus cycles, error-detection mechanisms, access and arbitration protocols, and identification mechanisms.

Conductive Transmission Media

Metallic conductors are used to carry electrical signals:

- **Printed Circuit Board Traces**: Specifically designed according to their intended function. Their electrical parameters depend on the particular design.
- **Twisted-Pair Cables**: Consist of one or more pairs of wires, usually twisted together to reduce the effects of electromagnetic interference coupling. When several pairs are bundled within the same cable, different twist rates are used to reduce crosstalk between pairs.
- **Coaxial Cable**: Consists of a central conductor and a metallic shield, surrounded by an outer insulating layer.



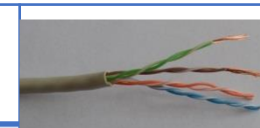
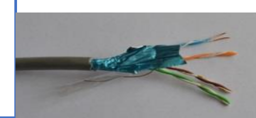
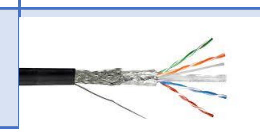


Twisted Pair vs. Coaxial Cable

Parameter	Coaxial Cable	Twisted-Pair Cable
Structure	Central conductor surrounded by an insulator, a metallic shield, and an outer jacket.	Two copper conductors twisted together to form a pair. A cable may contain several pairs.
Number of Conductors	**2 conductors** (central conductor + shield).	**2 conductors per pair**. Ethernet cables typically use 4 pairs (8 conductors).
Transmission	The signal travels along the central conductor and returns through the shield. It does not support differential signaling.	The signal travels through each pair of twisted conductors. It supports differential signaling.
Range / Distance	Longer; signals can be transmitted over hundreds of meters without repeaters, depending on the cable type and frequency.	Shorter; typically up to 100 m in Ethernet networks without intermediate equipment.
Resistance to Electromagnetic Interference (EMI)	Very high, thanks to the metallic shield that completely surrounds the conductor.	Moderate for UTP and high for STP/FTP (shielded cables), although generally lower than coaxial cable.
Cost	Higher, including the cable itself, connectors, and installation.	**Lower cost** and easier to install.
Main Applications	Television, antennas, CCTV, radio-frequency applications, and cable Internet.	Lower cost and easier to install.
Ease of Installation	Media; requiere mayor cuidado y conectores específicos.	Ethernet networks, telephony, data communications, and structured cabling.
Most Common Uses Today	Moderate; requires greater care and specific connectors.	High; easy to install and terminate.
Main Advantage	Television, radio-frequency applications, and some industrial installations.	Computer networks and building cabling.
Main Disadvantage	Excellent protection against interference and longer transmission range.	Low cost, ease of installation, and high data rates in local networks.

Types of Twisted-Pair Cables (ISO/IEC 11801)

Overall Shielding / Individual Pair Shielding:

U/UTP (Unshielded Twisted Pair): No shielding. Contains several twisted pairs (e.g., Ethernet).	
U/FTP (Foiled Twisted Pair): Each individual pair is foil-shielded to provide greater protection against incoming, outgoing, and mutual interference.	 *
F/UTP (Foiled Twisted Pair): A single overall foil shield surrounds all pairs.	
F/FTP (Foiled Foiled Twisted Pair): Each pair has an individual foil shield, with an additional overall foil shield around all pairs.	 **
S/FTP (Shielded/Foiled Twisted Pair): Combines an overall braided shield with individual foil shielding around each pair to improve electromagnetic protection.	
SF/UTP (Shielded Foiled Twisted Pair): Combines an overall braided shield with individual foil shielding around each pair to improve electromagnetic protection.	 ***

There is often some confusion regarding the use of these terms. See Annex E of the standard.

Structured Cabling (ANSI/TIA/EIA-568)

- Cat 1, 2: Voice.
- Cat 3, 4, 5, 6, 7 y 8: Data.

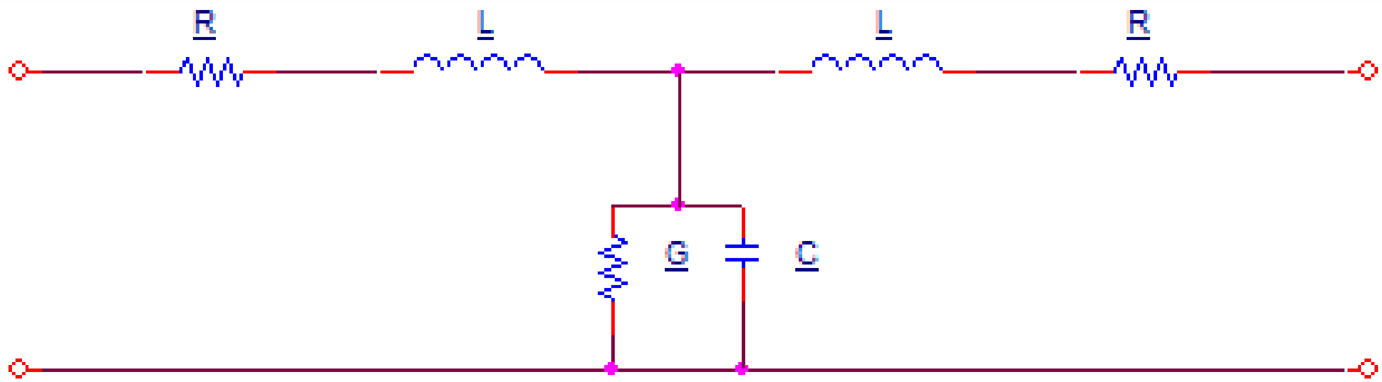
Category	Cable Type	Capacity
3	UTP	10 Mbps (10Base-T)
4	UTP	16Mbps (not commonly used)
5/5e	UTP	100 – 1000 Mbps (100Base-T, 1000base-T)
6/6A	UTP/F/UTP	Up to 10Gbps (10GBase-T)
7/7A	S/FTP/F/FTP	1 – 10Gbps (10GBase-T)
8.1/8.2	S/FTP/F/FTP	25 - 40Gbps (40GBase-T)

Xbase-T: x capacity in Mbps; base: baseband; T: twisted pair

UNIVERSIDAD DE BURGOS

Transmission-Line Fundamentals (I)

- Transmission lines are conductors that no longer behave as ideal connections and must instead be treated as more complex circuits.
- This phenomenon becomes relevant at high frequencies and/or over long distances. More specifically, transmission-line effects are generally considered significant when the cable length is greater than $\lambda/10$.



They are modeled using distributed parameters: $R(\Omega/m)$, $G(1/\Omega m)$, $L(H/m)$, $C(F/m)$

- With an open-circuit termination, all the energy is reflected back toward the source.
- With a short-circuit termination, all the energy is reflected back toward the source with inverted polarity.
- For an appropriately matched load, all the energy is absorbed by the load.

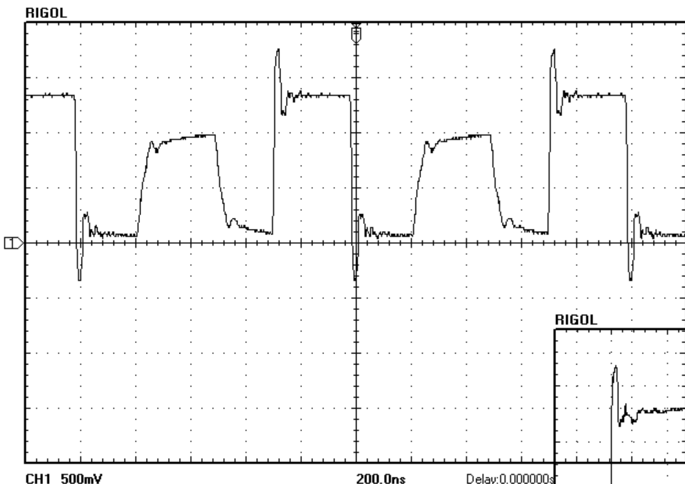
Transmission-Line Fundamentals (II)

- Characteristic Impedance: $Z_0 = \sqrt{\frac{R+j\omega L}{G+j\omega C}}$
- At Low Frequencies: $Z_0 \approx \sqrt{\frac{R}{G}}$ resistive.
- At High Freq.: $Z_0 \approx \sqrt{\frac{j\omega L}{j\omega C}} = \sqrt{\frac{L}{C}}$ resistive again.
- The line is matched using a terminating resistor $\mathbf{R} = \sqrt{\frac{\boldsymbol{L}}{\boldsymbol{C}}}$

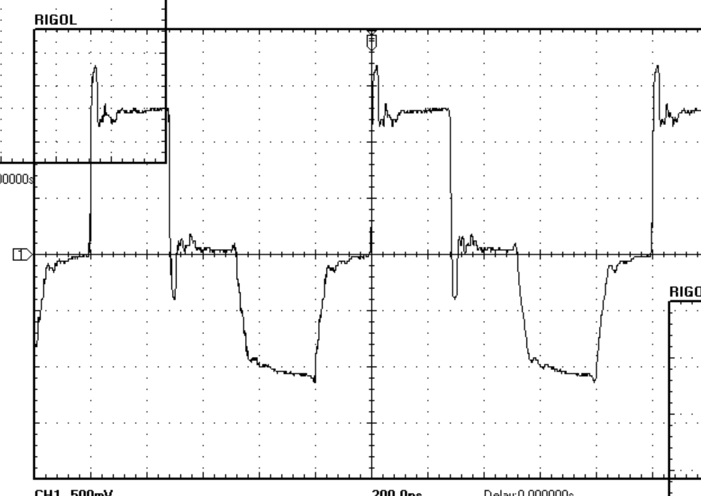
For more information, check: http://www.home.agilent.com/agilent/editorial.jspx?ckey=876888&id=876888&nid=-34785.0.00&lc=eng&cc=GB

Transmission-Line Fundamentals (III)

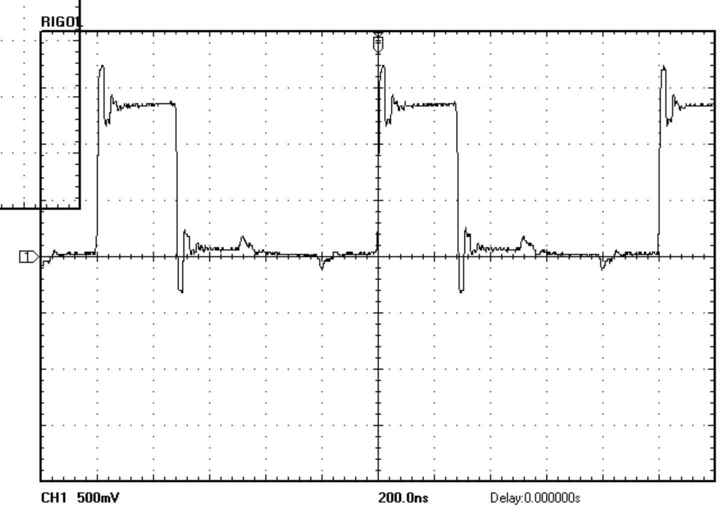
1 MHz signal, *0 – 2.5V.* Pulse width *0.3 µs.* Signal measured at the generator. Coaxial cable RG-58 50 meters. $Z_0 = 50\Omega$



Open-Circuit Line. All the energy is reflected back toward the generator.



Short-Circuit Line. All the energy is reflected back toward the generator with inverted polarity.

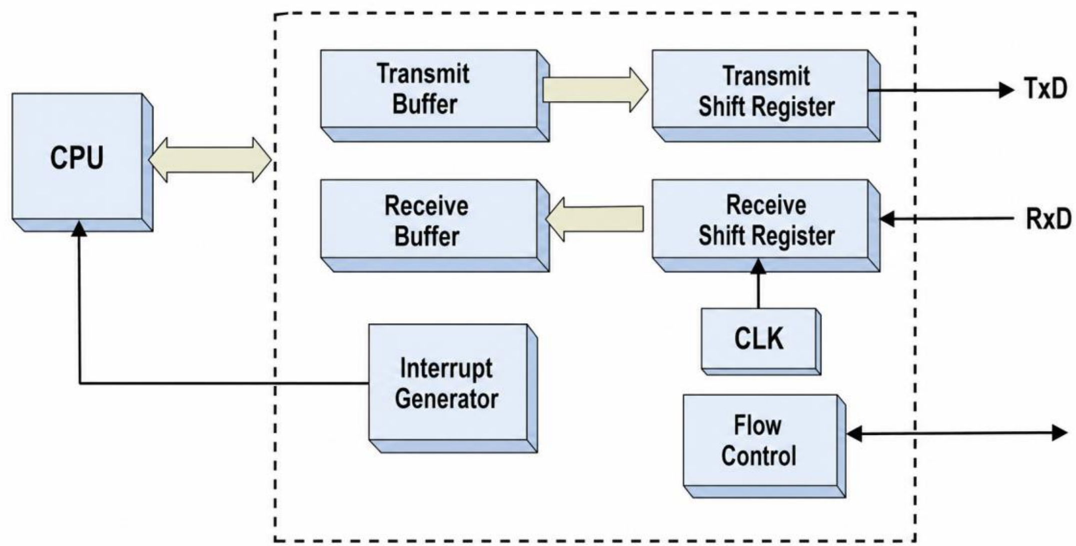


Matched Line. All the energy is absorbed by the load.

Serial Communication

- Serial communication is a communication system in which bits are transmitted sequentially over the same communication channel.
- It requires fewer communication lines than parallel transmission, making it particularly suitable for longer distances and reducing wiring complexity
- Serial communication may be synchronous or asynchronous, depending on how the transmitter and receiver are synchronized

UART
(Universal Asynchrounous Receiver/Transmitter)



TxD and RxD can be connected directly or to a transceiver to change the communication protocol, e.g., Bluetooth.

The use of flow-control lines is usually optional.

Transmission:

1. The CPU writes to the transmit buffer.
2. The data is transferred to the shift register to be serialized.
3. The data is transmitted bit by bit.
4. An interrupt can be generated each time a data item leaves the device.

Reception:

1. Data arrives at the shift register bit by bit.
2. It is converted into parallel form and transferred to the receive buffer.
3. An interrupt is generated to notify the CPU that data has been received.
4. The CPU reads the data, which is then automatically removed from the buffer.

Buses Used in Electronics

- Integrated-Circuit Communication Buses. Designed for short distances and low data-transfer rates: SPI, I^2C.
- Control Buses. Used for real-time device control, with bounded response times: CAN, LIN, RS-485.
- Instrumentation Buses. Used to transfer large amounts of information without requiring bounded response times: LXI.

I^2C (Inter Integrated Circuit)

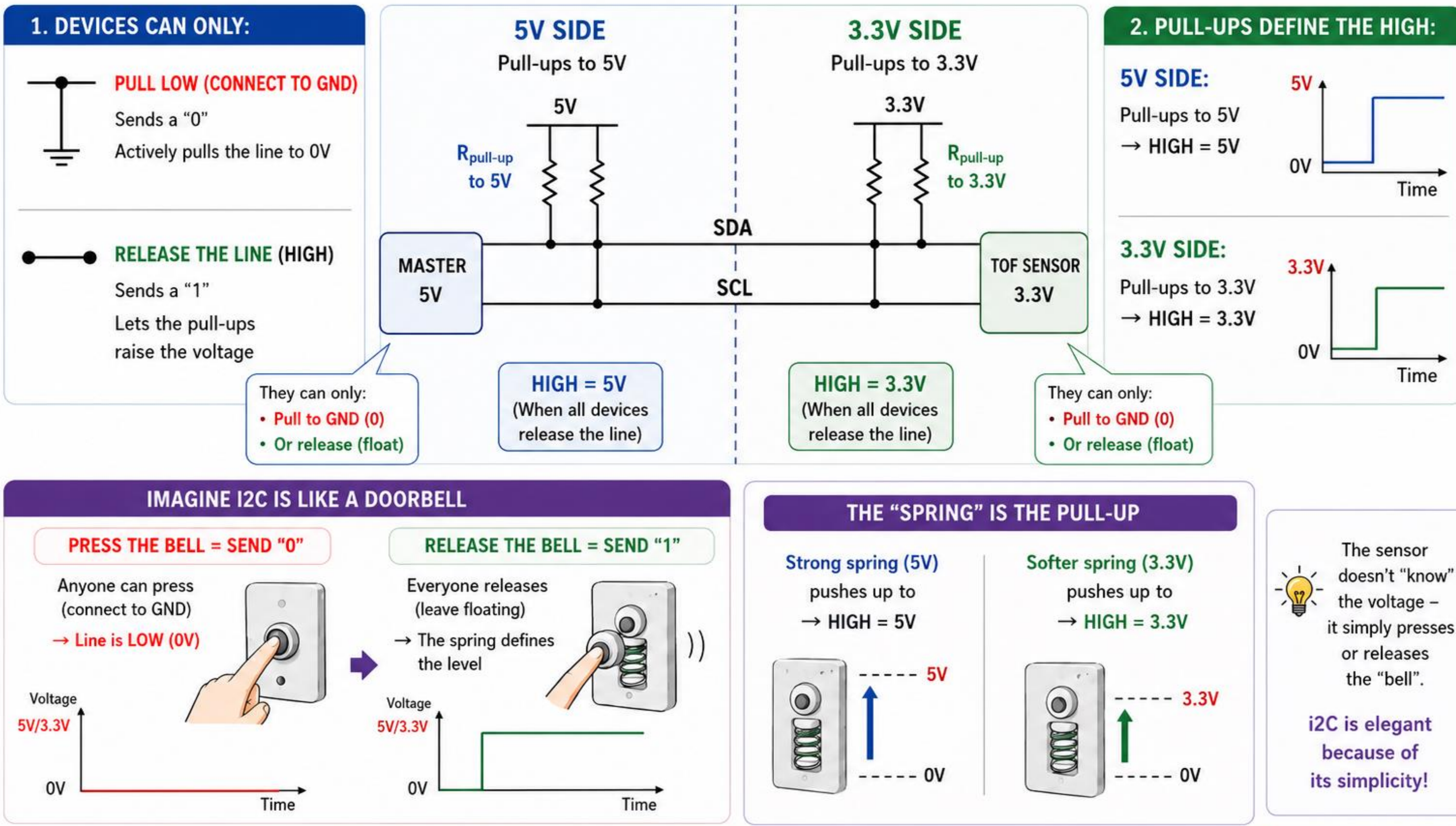
- Serial bus.
- Serial bus (**half-duplex**):
  - SDA (Serial Data).
  - SCL (Serial Clock).
  - VDD and GND can be added if required.
- Synchronous bus. Speed:
  - Slow: <=100kbps
  - Fast: <=400kbps
  - High speed: <=3,4Mbps
  - Ultra fast: <=5Mbps
- The bus length is limited by the maximum capacitance allowed for the selected data-transfer rate.

I²C (II)

- Connected devices can be transmitters, receivers, or both.
- They can also be masters (capable of initiating a transfer) or slaves. Masters can also behave as slaves when addressed by another master.
- Each device, regardless of its type, has a unique address.
- The clock signal is generated by the master.
- The connections use open-collector outputs, so an external pull-up resistor is required.
- Transmission is byte-oriented. An ACK signal must be sent after each byte.
- Arbitration is distributed. Two masters can initiate a transfer at the same time. The first one that “sees” a 0 on the bus when it has transmitted a 1 loses arbitration and withdraws.

HOW DOES THE I2C BUS WORK WITH DIFFERENT VOLTAGES?

All devices can only pull the line LOW (0) or release it → Pull-up resistors define the HIGH



SUMMARY: I2C devices are "simple" – they only pull (LOW) or release (HIGH). Pull-up resistors determine the HIGH voltage.

UNIVERSIDAD DE BURGOS

SPI (Serial Peripheral Interface)

- Serial bus.
- Minimum of 4 wires (full-duplex). Actually, 3 + “number of slaves”.
  - MOSI: Master Data Output.
  - MISO: Master Data Input.
  - SCLK: Master Clock.
  - SS: Slave Select (1 per slave).
- Slaves can be daisy-chained to prevent the number of select lines from becoming excessive.
- Synchronous bus. Multiple data-transfer rates.
- Only one master can be connected, so arbitration is not required.
- Supports 8-, 16-, and 32-bit transfers.

CAN (Controller Area Network) I

- Versatile specification for control networks.
- The physical layer is not specified. It is a single-channel serial bus
- The number of devices that can be connected is limited by propagation delay or electrical constraints.
- Up to 1 Mbps.
- Message-oriented.
- Each message has an “IDENTIFIER” that identifies its content.
- Messages do not contain destination information. Nodes must determine whether a message is relevant to them based on its IDENTIFIER. This is known as “message filtering”.

CAN (Controller Area Network) II

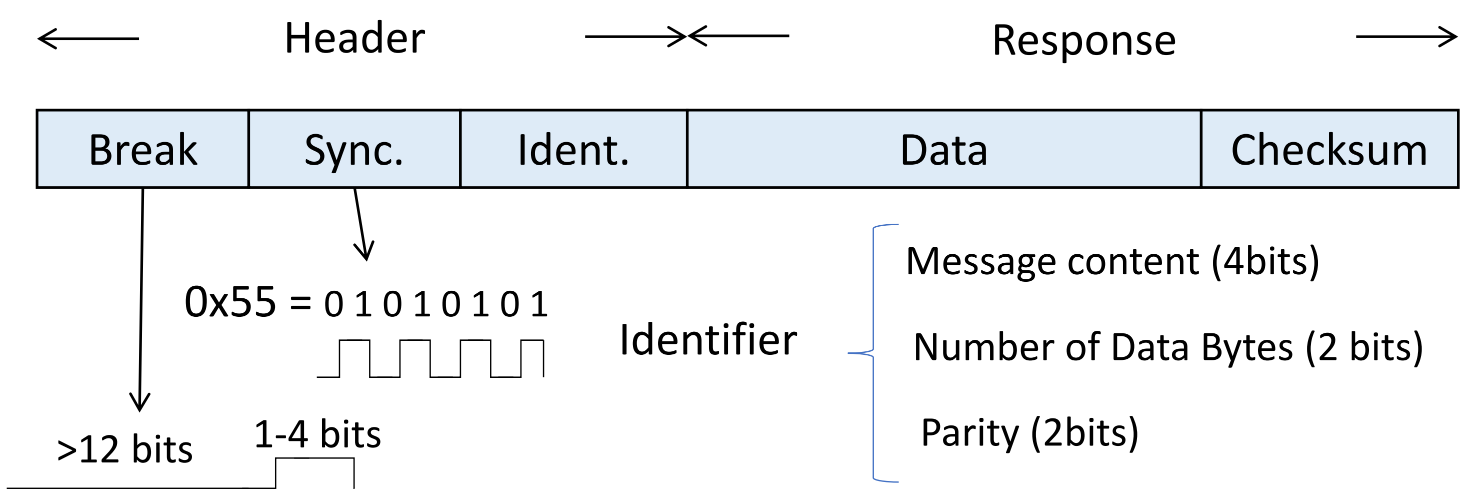
- The IDENTIFIER is also used as a priority mechanism in a distributed arbitration scheme. When two devices attempt to initiate a transmission at the same time, the first one that “sees” a 1 when it transmits a 0 must withdraw.
- Several cascaded protection mechanisms make it possible to achieve a final error rate <=$4,7*10^{-11}$.
- All received messages must be acknowledged or marked as erroneous.
- Devices can be put into “sleep” mode to reduce power consumption. An internal condition or the detection of bus activity can wake them up.

LIN (Local Interconnect Network) I

- Low-cost serial bus for automotive applications.
- Designed to replace the CAN bus when CAN is excessively expensive to implement (power windows, seats, etc.). Any low-cost microcontroller can support it.
- Supports a single master.
- Self-synchronized. The clock is derived from the master through an initial transmission of 0x55h. Slaves do not require an internal oscillator.
- Up to 20 kpbs.
- Uses a single wire (GND is available throughout the vehicle).

LIN (Local Interconnect Network) II

- Transmission is based on sending “frames”. Frame: Header + Response. Both include error protection.
- Headers are generated by a master task.
- Message filtering is used, as in CAN.
- Responses are generated by slave tasks. The master device implements both a master task and a slave task to enable information exchange with the slaves.



RS-485

- Together with RS-422, it is solely a physical-layer protocol.
- Numerous higher-level communication protocols used in industrial environments use this specification.
- It is strongly oriented toward industrial environments:
  - Long distances.
  - Highly noisy environments.
- As a result, the following aspects are covered:
  - Twisted-pair cable.
  - Balanced data lines.
  - Termination impedance.
  - Maximum distance (1,200 m).
  - Maximum number of connected devices (32).

I^2C/UART/SPI Problems in Industrial Environments

- I^2C is designed for communication within a printed circuit board or between boards located very close to each other.
- Its SDA and SCL lines are single-ended and are sensitive to noise.
- A microcontroller cannot reliably transmit a signal over several meters of cable using I^2C or TTL UART directly.

Solution: the protocol is not replaced; instead, an additional layer is added using an RS-485 transceiver, for example the MAX487, between the microcontroller and the cable. Advantages. Advantages:

- ✔ Communication over distances of up to 1,200 m.
- ✔ High noise immunity.
- ✔ Ideal for industrial environments (motors, variable-frequency drives,…)
- ✔ Multipoint communication (multiple devices on the same bus).
- ✔ Data rates up to 2.5 Mbps.

Wireless Communications I

They enable electronic devices to be connected without wires.

Depending on their complexity and power, they can provide different services and communication ranges:

- Medium-range wireless local area networks (Wi-Fi): IEEE 802.11.
- Short-range, high-speed wireless communications (Bluetooth): IEEE 802.15.1.
- Medium-range, very-low-power sensor and actuator networks (ZigBee): IEEE 802.15.4.

Comunicaciones inalámbricas II

	ZigBee	Wifi	Bluetooth	Bluetooth Smart
Standard	802.15.4	802.11	802.15.1	802.15.1
Application	Monitoring and control (sensor networks)	Web, e-mail, multimedia	Cable replacement	Healthcare, sports, sensors
Battery Life	100 – 1000 days	1 – 5 days	1 – 7 days	7 – 30 days
Nodes	65.536	2007	8	Not defined (mesh network)
Bandwidth	250 kbps	54Mbps	> 1Mbps	1Mbps
Range	100 m	100 m	10 m	> 10 m
Advantages	Power consumption, cost	Speed, flexibility	Cost	Power consumption, cost

ZigBee (I)

- Wireless communication standard.
- Developed by the ZigBee Allianc.
- Operates in the license-free ISM (Industrial, Scientific & Medical) bands.
- Data rate of 250 Kbps.
- Coverage of up to 75 m. Greater distances can be achieved by using nodes as repeaters.
- Up to 16,000 networks can coexist on the same channel through the use of network identifiers.
- Up to 65,000 devices per network.
- Mesh topology to provide fault tolerance.
- Designed for low power consumption at the nodes → increased battery life.

ZigBee (II)

Three types of devices are defined:

- **Coordinator**: There is one per network. It is responsible for starting the network and is capable of routing traffic to other networks.
- **Router**: Routes traffic to other networks, but can also execute user code.
- **End Device**: Executes user code and has only the communication capabilities required to connect to its coordinator or router, minimizing cost and power consumption.

ZibBee (III)

Routing:

- Routers maintain a destination table in which they store both the logical distance to the destination node and the next router along the path.
- The table is populated using a route-discovery mechanism.
- The source router sends a broadcast containing the route-request command.
- When the command reaches the destination node, the route is returned to the source.

UNIVERSIDAD DE BURGOS

References

- ISO/IEC 11801: Information technology –Generic cabling for customer premises.
- CAT 6A F/UTP vs. UTP: What You Need to Know. BlackBox Network Services. 2010.
- UM10204. I2C-bus specification and user manual. Rev. 5. NXP Semiconductors.
- Interfacing using Serial Protocols. Using SPI and I2C. P. Myers. EMRT Consultants.
- CAN Specification. V 2.0. Robert Bosch GmbH. 1991.
- LIN Specification standards and specifications https://www.lin-cia.org/standards/
- Introduction to the Local Interconnect Network (LIN) Bus. National Instruments white paper. 2011.
- RS-422 and RS-485 Standards Overview and System Configurations. Texas Instruments Technical Report. 2002 rev. 2010.
- LXI Device Specification 2011. LXI Consortium, Inc.
- What is LXI?. National Instruments white paper. 2011.
- BLUETOOTH SPECIFICATION Version 4.2. Dec 02 2014. Bluetooth SIG Proprietary
- Zigbee / IEEE 802.15.4 Standard. Dusan Stevanovic. ZigBee Alliance. June 2007.
- Getting Started with ZigBee and IEEE 802.15.4. Daintree Networks.